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AN APPLICATION OF TAGUCHI'S METHOD FOR OPTIMIZATION OF PROCESS PARAMETERS: A CASE STUDY OF CAST IRON SAND CASTING

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ABSTRACT

The OBJECTIVE of the research is to apply Taguchi's method for optimization of the process parameters of cast iron sand casting using. An attempt has been done to obtain optimal settings of the green sand casting process in order to produce the optimum quality characteristics of the cast iron sand casting. The process parameters considered are moisture content, green strength, permeability number and mould hardness number. The effect of selected process parameters and its levels on casting defects has been studied and the subsequent optimal settings of the parameters have been obtained using Taguchi's parameter design approach.

KEYWORDS: Taguchi's, Green Sand Casting Process, Cast Iron Sand Casting, Permeability Number and Mould Hardness Number

INTRODUCTION

In the current aggressive atmosphere, it is of supreme substance to preserve the quality of the castings and to endeavour at products with 'zero-defect' and 'right the first time'. Genichi Taguchi, a quality management expert from Japan laid foundation of a new method for quality improvement, in the 1950's and the early 1960's. According to Taguchi the important building block for attaining high quality at lower cost to have optimum level of process parameters.

Process parameters are also known as control factors should be selected in a manner such that the weight of uncontrollable or noise factors causes minimum variation of system performance. These parameters should be controlled to improve the quality of both casting process and product. A number of problems of various types are associated with the casting process. These problems may be related to casting yield, defects, dimensional variations, surface texture and so on. If the process of casting is not handled appropriately, the problems may intensify further resulting in defects which leave the product feeble and of low quality, thus, making them unsuitable for use.

In Taguchi's approach, quality is measured by the deviation of a quality characteristic from its target value. Uncontrollable factors, known as noise, cause such deviation and there-by lead to loss. Since the total removal of noise factors is unrealistic and often unfeasible, Taguchi method tries to reduce the consequences of noise and establish the optimal level of the important controllable factors based on the concept of robustness.

The overall aim of this research is to minimize defects in Aluminium sand casting by analyzing various significant process parameters of the green sand casting process. An effort has been made to find optimal settings of the green sand casting process parameters that yield the optimum quality of cast iron casting .The process parameters considered are moisture content, green strength, permeability and mould hardness.

LITERATURE REVIEW

Quality enhancement in foundry industry have been done by researchers and foundry engineers for strong products at the eyes of customers by using a variety of optimization techniques like Taguchi's method. Taguchi has pioneered in a number of statistical tools and ideas of quality enhancement that depend profoundly on the statistical theory of experimental design .Some uses of Taguchi's method in the foundry industry have revealed that the difference in casting quality caused by uncontrollable process variables which can be minimized.

The notion of strong projects for both the process and the product has been put forward by Genichi Taguchi which intends to make both the process and the product insensitive by arresting the source of variations that could pilot to defects in the products.

Barua et al. [1] applied the Taguchi's method to find optimum mechanical properties of the Vacuum V-casting process. In their research, they mulled over the consequences of the vital process parameters on the mechanical properties of alloy casting which helped in setting optimal parameters, which were achieved applying Taguchi's parameter design process. Changyu et al. [2] also proposed a combining artificial neural network and genetic algorithm method to optimize the injection moulding process. Enright and Prince [3] developed a simple mathematical model to study effects of liquid metal flow, transient heat transfer, and foam degradation during casting process. Frayce et al. [4] explaind the problems in numerical simulation of the die casting process and proposed Prometheus- 3D for the calculation of filling patterns for casting. Jolly et al. [5] analyzed Numerical simulators based on FDM and FEM methods, provided powerful means of analyzing various phenomena occurring during the casting process. Juran et al. [6] stated that control factors are the selected independent variables of the experiment, which have different effects on the response variables when adjusted to different levels. They can be subdivided into quantitative control factors and qualitative control factors. Noise factors are the variables, which influence the response variables. They may or may not be known. Special care should be taken to prevent the noise factors from interfering in the experimental results. Lipinski et al. [7] presented the numerical basis of Magmasoft, a commercial finite difference solver for the simulation of casting. Masters et al. [8] described a robust design method for reducing cast and improving quality in an aluminium remelting process.

An experimental examination to the process parameter effect was offered to establish the optimum arrangement of design parameters for performance, quality and cast. Minaie et al. [9] deliberated the flow characteristics and related solidification properties all through the die casting process by taking into account continuity, transport of momentum and energy. The model developed for the investigation in the flow field was capable to offer helpful information for the arrangement of the gates and overflows by which diverse areas of the die cavity were filled. Muzammil et al. [10] in their research optimize a gear blank casting process applying Taguchi's robust design approach. In their investigation, they revealed that the process of casting having a number of parameters upsetting the a variety of cast characteristics of the product. Papai and Mobley [11] have done comprehensive temperature measurements in die casting dies, which results in optimum setting of various process parameters, such as the heat transfer coefficient at the edge of casting-die is determined . Syrcos [12] in his research examined different vital process parameters of the die casting process of aluminium alloy which farther helped in optimal settings of the die casting parameters that produce the optimal casting density of the aluminium alloy castings. Sulaiman and Gethin [13] used a network for metal flow analysis in the pressure die casting process to predict the metal flow characteristics in the filling system by simplifying the complex Navier– Strokes equation. Rao et al. [14] developed a three-layer back-propagation neural network to extract the complex relationship involved in

hot-deformation process modelling. By developing the network, it helped greatly not only in reducing the number of experiments required to characterize a material's behaviour but also reduced the problems associated with empirical, semi-empirical constitutive models that involve the evaluation of a large number of constants. In addition to the casting process, the Taguchi method may be applied for the variety of processes such as milling, grinding and the machining of composites etc. Ghani et al. [15] applied the Taguchi method for the optimization of end- milling process parameters for hardened steel specimen with. They applied it to optimize cutting parameters in end milling when machining hardened steel with tin-coated carbide insert. Shaji and Radhakrishnan [16] have done detailed investigation of the process parameters for surface grinding operation using the Taguchi method. They examined the process parameters namely speed, feed, and method of dressing on the surface finish of machined specimen. Der Ho Wu et al. [18] used successfully the Taguchi's method to find out the optimum process parameters for the die casting of thin-walled magnesium alloy components. The results confirmed the effectiveness of robust design methodology. Sushil Kumar et al. [19] have carried out an optimization technique for process parameters of green sand casting of a cast iron differential housing cover based on Taguchi parameter design which indicated in determining the best casting parameters for differential housing cover.

Pradeep Kumar et al. [23] applied the Taguchi's approach to the vacuum sealed process to obtain an optimal setting of the control factors that yielded the optimum surface roughness of the Al – 11 per cent Si alloy castings. Muzammil et al. [10] made a study for optimization of Gear Blank Casting Process by Using Taguchi's Robust Design Technique. In this study they demonstrated that casting process involve a large number of parameters affecting the various casting quality features of the product. The reduction in the weight of the casting as compared to the target weight was taken to be proportional to the casting defects. B. H. Kim et al. [35] in their study, the relationship between casting process parameters and mechanical properties in a 14.5% Si containing corrosion resistant cast iron was statistically investigated using Taguchi method. The effects of casting process parameters on mechanical properties and corrosion resistance were further confirmed by combined analysis of fractography, hydrogen content determination, microscopic test and acid resistance test. Ballal Yuvraj P. et al. [20] describes that in order to produce any product with desired quality proper selection of process parameters is essential. Dr. M. Arasu [21] the approach taken in this paper expects the foundries to use a standard classification system to describe undesirable casting artifacts for more effective failure analysis. It deals the various aspects of a systematic approach to understanding and development of quality cast system in cast iron foundries. A. Noorul Haq.et al. [22] in their study demonstrates optimization of CO_2 casting process parameters by using Taguchi's design of experiments method. The effect of the selected process parameters on casting defects and subsequent setting of the parameters are accomplished by using Taguchi's parameter design approach.

Anastasiou [27], investigated the effects of process parameters on porosity formation in the pressure die casting process to improve the quality of casting through Taguchi method. Different Process parameters such as plunger velocity & Die temperature were optimized to enhance quality and cut down cast applying Taguchi's method. Sushil Kumar ,[19] proposed a method of optimization of green sand casting using Taguchi's method in which input parameters were Moisture, Green strength, Pouring temperature, Mould hardness vertical, Mould hardness horizontal and the material used was cast iron.

With the help of the orthogonal array the numbers of interactions were selected and ANOVA was done with the help of which the values of confidence limit were obtained. If the average of the results of the confirmation experiment is outside the range of the CI, the parameters selected and/or levels to control the results for a desired value are incorrect.

Mekonnen Liben [30] proposed a method of optimization of Aluminium blank sand casting using Taguchi’s method. Rahul C Bhedasgaonkar [31], proposed a method of analysis of casting defects by Design of experiments and Casting Simulation technique. The methodology used for reduction in % rejection of selected casting pipe turbocharger by minimizing the casting defects in green sand moulding and related to moulding sand using design of experiments method such as Taguchi method and elimination of defect occurring due to faulty methoding such as shrinkage by casting simulation technique. The response variable was % rejection of casting due to defects related to moulding process such as sand drop, bad mould, blow holes, scab, cuts and washes. Kumaravadivel [32] suggested a process window approach to optimize sand casting.

TAGUCHI’S METHOD

An approach to engineering that put emphasis on the roles of research and development, product design and product development in reducing the incidence of defects and failures in products.The Taguchi method believes

Process design to be fool proof which reduce variation in production process.Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods.

Taguchi’s work includes three standard contributions to statistics:

- A specific loss function.
- The philosophy of off-line quality control.
- Innovations in the design of experiments.

ROBUST DESIGN

A main source of poor yield in manufacturing processes is the manufacturing variation. These manufacturing differences consist of difference in temperature or humidity, variation in raw materials, and drift in process parameters. These sources of noise / variation are the variables that are not viable or expensive to control.

The objective of the robust design is to find the controllable process parameter settings for which noise or variation has a minimal effect on the product's or process's functional characteristics. It is to be noted that the aim is not to find the parameter settings for the uncontrollable noise variables, but the controllable design variables. To attain this objective, the control parameters, also known as inner array variables, are systematically varied as stipulated by the inner orthogonal array. The level combinations of noise variables are done using the outer orthogonal array.

The effect of noise on the performance can be found using the ratio S/N where S is the standard deviation of the performance parameters for every inner array experiment conducted and N is the total number of experiment in the outer orthogonal array.This ratio point towards the functional variation because of the noise. With the help of S/N ration, it is achievable to forecast the control parameter settings which will make the process not sensitive to noise. This is true in case of experiments which are conducted using the computer simulation as the repeatability of a computer simulated experiments is very high

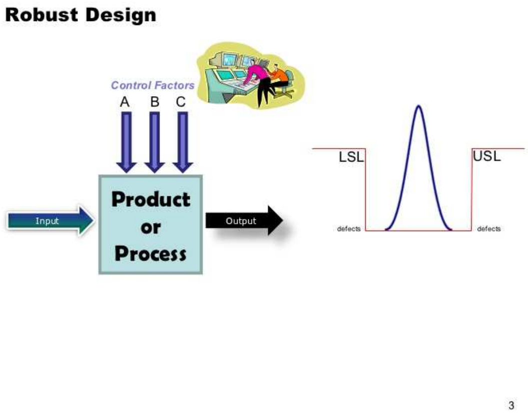


Figure 1: Robust Design

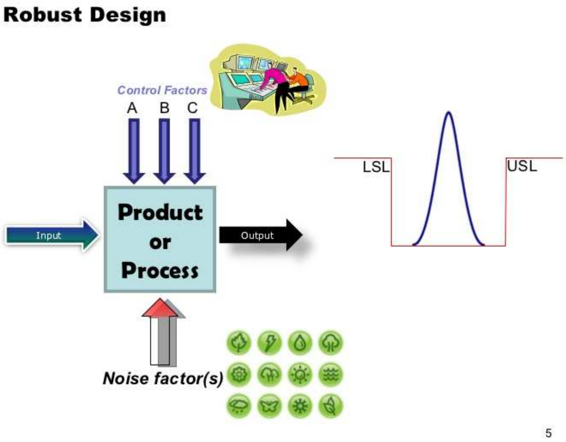


Figure 2: Robust Design (Noise Factors)

TAGUCHI'S METHODOLOGY

Dr. Taguchi has suggested a method based on experiments of orthogonal array which gives lesser variation with optimal settings of experimental parameters. As a result the blend of experimental design together with optimum control parameters helps in obtaining the best results Orthogonal arrays (OA) gives a set of well poised experiments and signal-to-noise ratios (S/N), which are log functions of output, commonly known as objective functions. Optimization of objective function under a set of the constraints helps in optimization of process parameters.

- Taguchi's Method classify the optimization problems into two categories
- Static problems
- Dynamic problems

STATIC PROBLEM

A process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a static problem.

Dynamic problem

If the product to be optimized has a signal input that directly decides the output, the optimization involves determining the best control factor levels so that the input signal / output ratio is closest to the desired relationship. Such a problem is called as a dynamic problem.

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems.

Smaller the Better

- n = -10 Log_{10} [mean of sum of squares of measured data]
- This is usually the chosen S/N ratio for all undesirable characteristics like defects etc.

Larger the Better

n = -10 Log_{10} [mean of sum squares of reciprocal of measured data]

Nominal the Best

n = 10 Log_{10} [square of mean/variance]

BENEFITS OF TAGUCHI'S METHOD

Taguchi Methods allow a company to rapidly and accurately acquire technical information to design and produce low-cast, highly reliable products and processes. Its most advanced applications allow engineers to develop flexible technology for the design and production of families of high quality products, greatly reducing research, development, and delivery time.

Taguchi Methods has a new way of thinking about product development. These methods differ from others in that the methods for dealing with quality problems center on the design stage of product development, and express quality and cast improvement in monetary terms. It includes both upstream and shop-floor quality engineering. In addition to it, it lays emphasis on key parameters which has more effect on the experiment plus it helps in experimenting different parameters with a high amount of experimentation.

TERMINOLOGIES USED IN TAGUCHI'S METHOD

ORTHOGONAL ARRAY

These are special matrices which allow the effect of several parameters to be determined efficiently. Here orthogonality refers in the combinatoric sense that is for any pair of columns, all combinations of factor levels occur and they occurs an equal number of times. This is called balancing property and it implies orthogonality.

These are used for variety of factors:

- To study the effect of control factors
- To evaluate the s/n ratio
- To determine the best quality characteristic for particular application before constructing an array following things must be defined:

- Number of factors to be studied
- Number of levels for each factor
- Specific factor interactions to be estimated

Table 1: L9 Orthogonal Array

Test Case	Parameter 1	Parameter 2	Parameter 3
1	1	1	3
2	1	2	2
3	1	3	1
4	2	1	2
5	2	2	1
6	2	3	3
7	3	1	1
8	3	2	3
9	3	3	2

SIGNAL TO NOISE RATIO

Signal-to-noise ratio (often abbreviated SNR or S/N) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels.

- $SNR=P_{signal}/P_{noise}$
- Where P is average power.
- SNRs are often expressed using the logarithmic decibel scale. In decibels, the SNR is defined as:
- $SNR_{db}=10\log_{10}(P_{signal}/P_{noise})$

DEGREE OF FREEDOM

Total degrees of freedom are counted because it tells the minimum number of experiments to be performed to study all the chosen control factors. In mathematical terms degree of freedom is one less than the number of levels for that factor. for example if no. of levels are n_A then degree of freedom would be (n_A-1).

ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal.The ANOVA Table (or Analysis Of Variance) table gives us the following information:

- Degrees of freedom
- The Sum of squares
- The Mean Square
- The F ratio

- The p-value

Table 2: Example of ANOVA Table

Source	Degree of Freedom	Sum of Squares	Variance	F Ratio

EXPERIMENTAL DETAILS (CASE STUDY)

To perform the Taguchi's analysis, an experiment of green sand casting has been done in workshop.The details of which has been given below

PROCESS PLANNING

Input Parameters

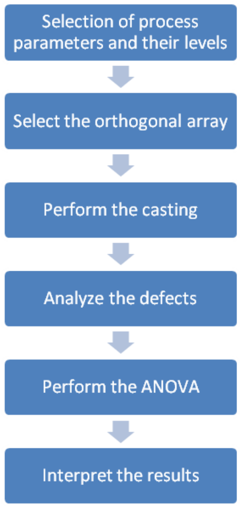
- Moisture content
- Green strength
- Permeability number
- Mould hardness number

Table 3: Process Parameters and their levels

Parameter Designation	Process Parameters	Range	Level 1	Level 2	Level 3
A	Moisture (%)	2.6-3.0	2.6	3.0	-
B	Green strength(g/cm^2)	650-950	650	800	950
C	Permeability number	235-265	235	250	265
D	Mould hardness number	70-90	70	80	90

- **Output**: Quality characteristics
- **Method used**: Green sand casting
- **Material used**: Cast Iron
- **No of trials**: 18 with 2 replications each

APPROACH



Flowchart showing approach used in research

EXPERIMENTAL PROCEDURE

The whole experimental procedure has been divided into certain steps. These steps have been explained as follows:

- Pattern making
- Melting of metal
- Mould making, pouring and solidification of casting
- Inspection of defects

Patttern Making

A pattern is a replica of the object to be cast, used to prepare the cavity into which molten material will be poured during the casting process; the pattern has been made of wood with suitable allowances.

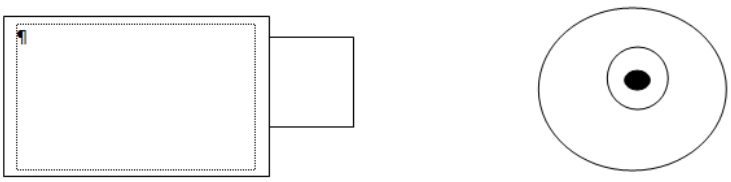


Figure 3: Side View and Front View of Pattern

MELTING OF METAL

There are a variety of methods used in foundries for melting the metal for casting. The selection of an appropriate technique is dependent on factors such as the metal being melted, the amount of molten metal required for the production run and the area available to house the melting equipment.

In this research melting of metal (Cast Iron) has been done in crucible furnace which is available in the foundry lab of mechanical engineering department.

MOULD MAKING, POURING AND SOLIDIFICATION OF CASTING

- **Step 1-**Place pattern in flask with enough room for gating.
- **Step 2-** Dust pattern with parting dust to keep it from sticking. Parting dust is a hydrophobic material, it repels moisture.
- **Step 3-** Use a fine riddle to cover just the pattern, then fill up the flask with sand, level (flush) with the top. There is no need to riddle all the sand, just make sure there are no lumps.
- **Step 4**- Use rammer to tuck edges first. Hold the flask with your other hand.
- **Step 5-** Again fill the flask with sand and smoothen it out with rammer.
- **Step 6**-Place bottom board on top of your mould. Holding bottom board and flask together, flip it over.
- **Step 7-**Remove the cope and pattern board, smoothen out the edges of the pattern and any rough areas.
- **Step 8-** Replace cope and apply parting dust to keep the cope/drag separated, again fill it with sand and do the ramming.
- **Step 9-**Take cope off and set it aside.
- **Step 10-**Form sprue hole.
- **Step 11**- Carve pouring cup into the sprue hole on the top of the mould.
- **Step 12-** Clean rough areas around sprue , tap runner pattern to loosen, then remove.
- **Step 13**- Remove gate and tap pattern lightly to loosen after that remove pattern and replace the cope.
- **Step 14-** Remove the flask and pour the molten metal into the mould.
- **Step 15-** Allow mould to cool, shake out the mould and remove casting, cut off gating system.

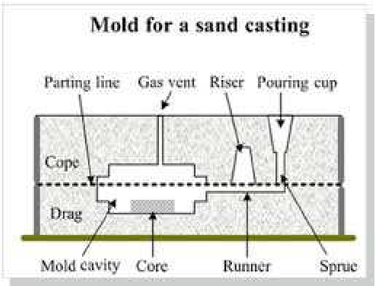
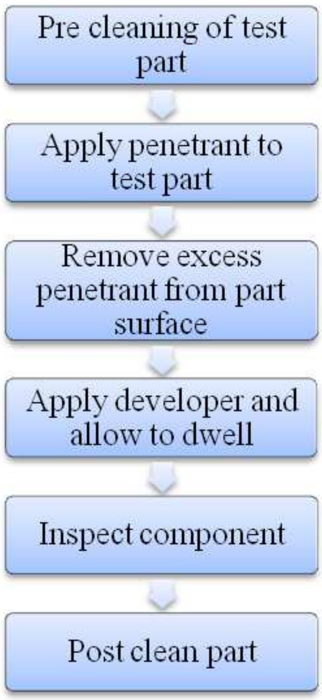


Figure 4: Mould for Sand Casting

INSPECTION OF DEFECTS

The castings produced have been checked for surface defects, surface defects can be inspected by naked eye or non destructive tests like that of die penetration test. The die penetration test has been done in non destructive testing lab. The test consisted of certain steps which are described as follows:

- Precleaning
- Application of penetrant
- Removal of excess penetrant
- Application of developer
- Dwell
- Inspection
- Post cleaning



Flow chart for die penetration testing¶

Figure 5: Die Penetration Test Chemicals

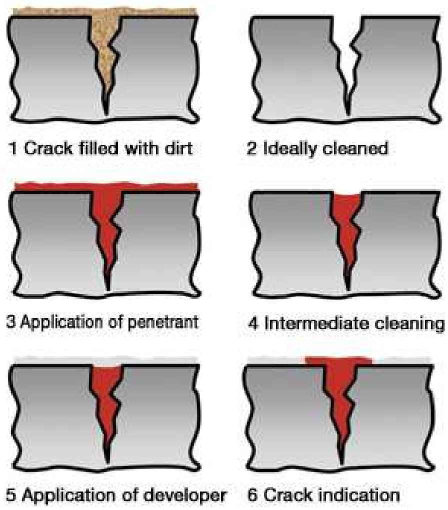


Figure 6: Die Penetration Test

OBSERVATIONS

The defects that have been observed after castings are as follows:

- Pinholes
- Joint Flash or Fin
- Shrinkage cavities
- Metal penetration defect

PINHOLES

As the molten metal gets solidified it loses the temperature which decreases the solubility of gases and thereby expelling the dissolved gases. The hydrogen which is picked up by the molten metal either in the furnace from the unburnt fuel or by the dissociation of water inside the mould cavity may escape the solidifying metal leaving behind very small diameter and long pin holes showing the path of escape.

Figure 7: Pinholes

Joint Flash or Fin

Flat projection of irregular thickness, often with lacy edges, perpendicular to one of the faces of the casting.It occurs along the joint or parting line of the mould, at a core print, or wherever two elements of the mould intersect.

Figure 8: Joint Flash or Fin

Shrinkage Cavities

These are caused by the liquid shrinkage occurring during the solidification of the casting. A shrinkage cavity is a depression or an internal void in a casting that results from the volume contraction that occurs during solidification.

Figure 9: Shrinkage Cavity

METAL PENETRATION DEFECT

Molten metal enters into the space between the sand grains and results in metal penetration and rough casting surface. Its main causes are high permeability, soft ramming and large grain size sand.

Figure 10: Metal Penetration Defect

PERCENTAGE OF DEFECTS

The average percentage of defects according to 18 experiments with two replications each are tabulated in the following table:

Table 1: Average Percentage of Defects

Trial No.	Average Defects (%)
1	7.64
2	6.41
3	5.35
4	6.81
5	6.22

6	5.21
7	4.41
8	3.84
9	3.15
10	7.51
11	7.02
12	8.42
13	6.81
14	7.15
15	7.82
16	4.22
17	6.2
18	4.53

Degree of Freedom

The degree of freedom for 4 factors,3 factors at 3 levels and 1 factor at 2 level has been calculated in the following way:

Table 2: Total Degree of Freedom

Source of Degree of Freedom	Required Degree of Freedom
Overall mean	1
A **B,C,D**	2-1=1 3(3-1)=6
Total degree of freedom	8

Orthogonal Array

The standard orthogonal array on the basis of process parameter (4) and the number of levels (3 for 3 factors and 2 for 1 factor) has been chosen as L18 with the help of degrees of freedom. The number of degrees of freedom was 8 so the nearest array with respect to the given factor was L9 but the numbers of replications were 2, therefore the array chosen was L18

L18 Orthogonal Array

Table 3: L18 Orthogonal Array

Trial No.	A (Moisture Content)	B (Green Strength)	C (Permeability)	D (Mould Hardness)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2

14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

Experimental L18 Array

Table 4: Experimental L18 Orthogonal Array

Trial No.	A(Moisture Content)	B(Green Strength)	C(Permeability)	D(Mould Hardness)
1	2.6	650	235	70
2	2.6	650	250	80
3	2.6	650	265	90
4	2.6	800	250	90
5	2.6	800	265	70
6	2.6	800	235	80
7	2.6	950	235	90
8	2.6	950	250	70
9	2.6	950	265	80
10	3.0	650	265	70
11	3.0	650	235	80
12	3.0	650	250	90
13	3.0	800	265	80
14	3.0	800	235	90
15	3.0	800	250	70
16	3.0	950	250	80
17	3.0	950	265	90
18	3.0	950	235	70

RESULTS AND DISCUSSIONS

RESULT

The calculations for ANOVA have been done with the help of recorded values of percentage of defects and the values of process parameters. To find out the optimized results for the process parameters of the casting, Taguchi analysis has been done with the help of MINITAB 14(statistical software).

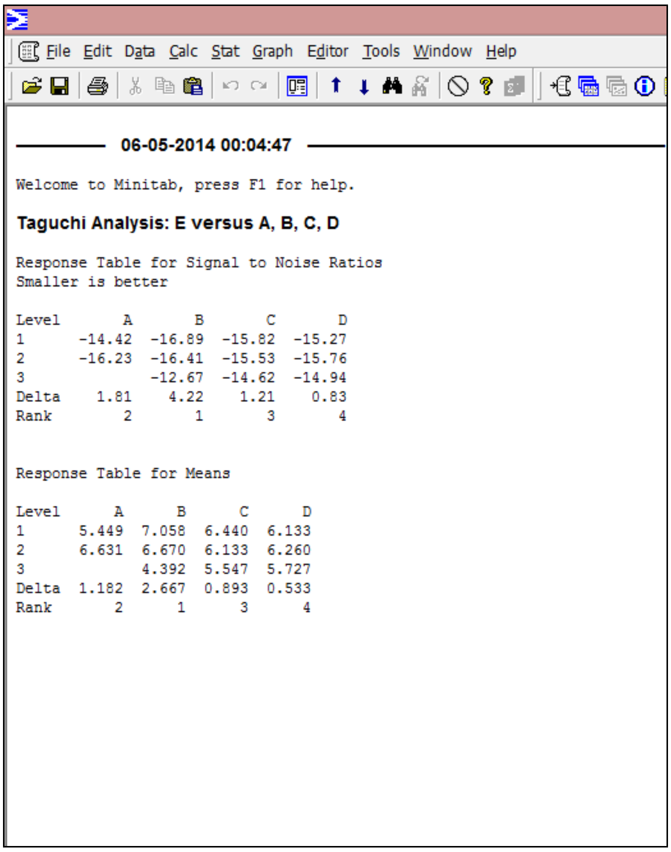


Figure 11: Taguchi Analysis (Screen)

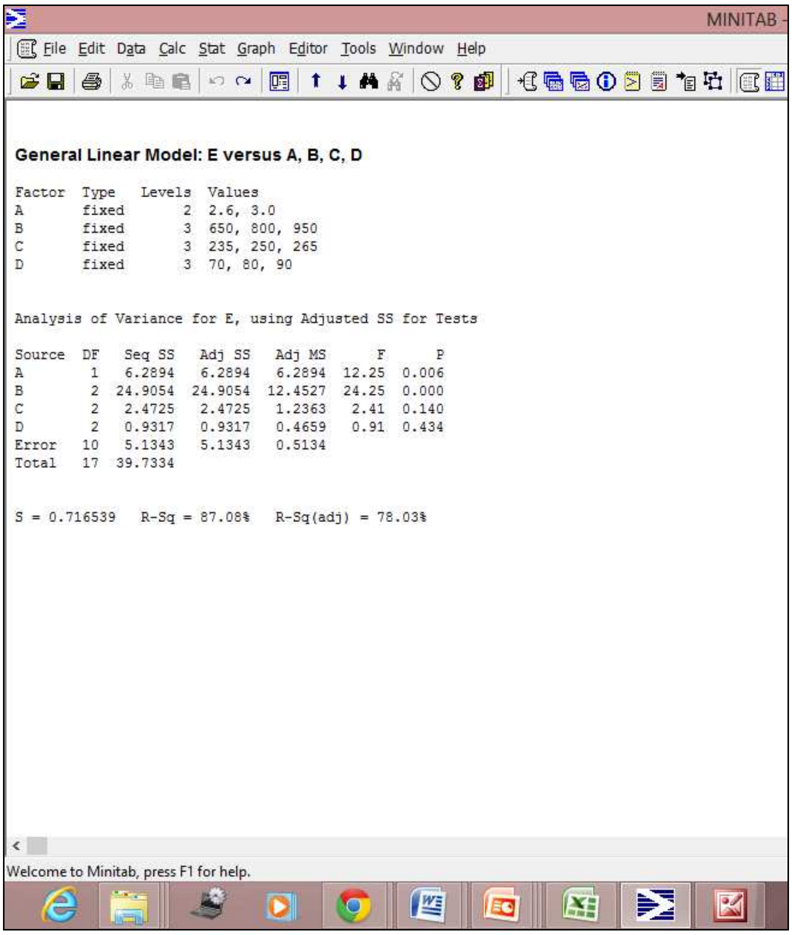


Figure 12: ANOVA (Screen)

After performing the Taguchi's analysis and ANOVA, Confidence interval has been calculated which predicts the optimum range of defects.

CONFIDENCE INTERVAL

A confidence interval (C.I) gives an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. Confidence interval is calculated on the basis of the following formula:

$$\textbf{C.I} = \{F(\alpha, 1, \upsilon e)\, V_e[1/\eta_{eff} + 1/r]\}^{1/2}$$

α = level of risk, [1-confidence limit(95%)]

V_e = error variance,

υ_e =degree of freedom of error ,

r = no of test trials,

η_{eff}= effective no. of replications.

F=critical F ratio (taken from F ratio table at appendix A)

Putting values in above formula we get the value of C.I as 1.38

Estimation of Mean (M) For Casting Defects

$\mu=T+(A_1-T)+(B_3-T)+(C_3-T)+(D_3-T)$

Where T is the average values of casting defects at different levels and A_1, B_3, C_3, D_3 is the average values of defects at of parameter A at level 1, B at level 3, C at level 3 and D at level 3, we have calculated the value of T which is 6.04 so the value of μ from the above formula would be 3.47%.

PREDICTED OPTIMAL RANGE OF DEFECTS

$\mu\text{-CI} < \mu < \mu + \text{CI}$

Putting the values of C.I and μ in above equation, we get

2.09 < 3.47 < 4.85

MAIN EFFECTS PLOT FOR S/N RATIO

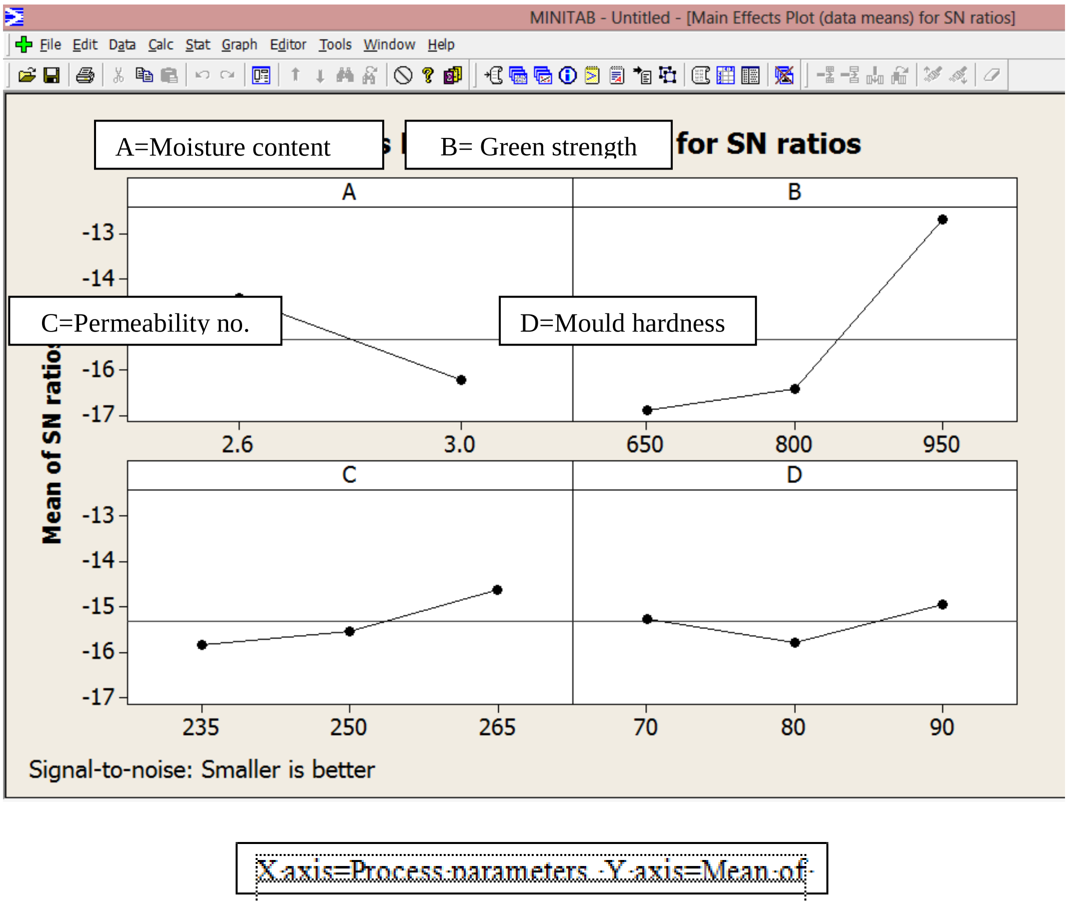
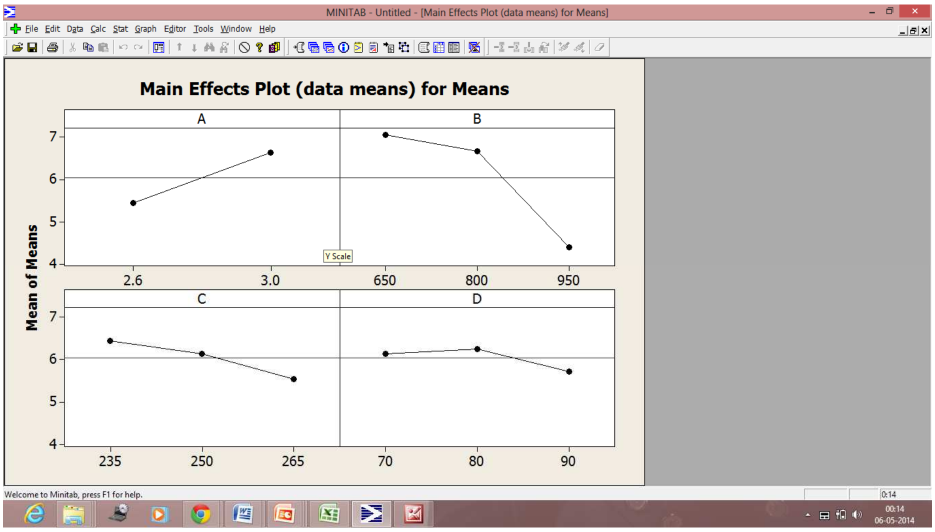


Figure 13: Main Effect Plot For S/N Ratio

Main Effect Plot for Means



X axis=Process parameters, Y axis=Mean of means¶

Figure 14: Main Effect Plot for Means

Normal Probability Plot for Residuals

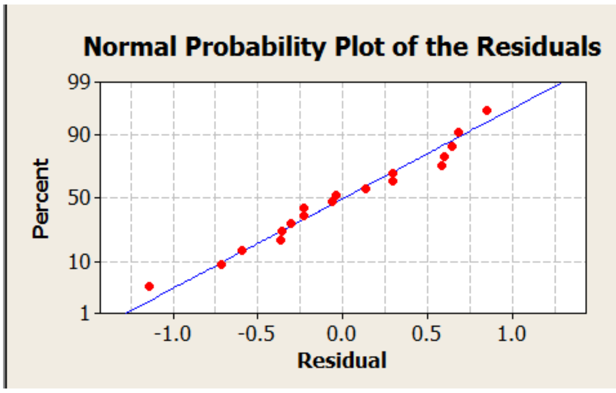


Figure 15: Probability Plot for Residuals

Residual Vs Fitted Value Graph

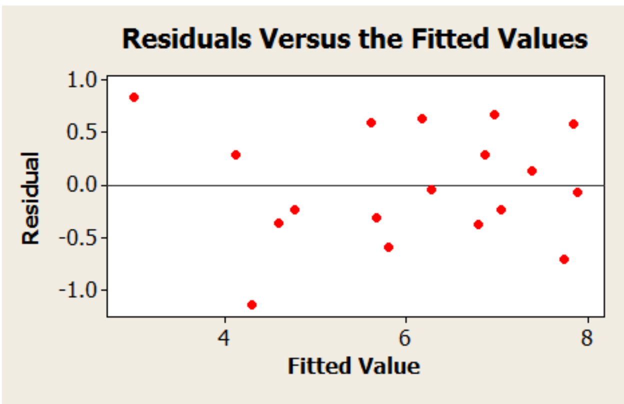


Figure 16: Residual Vs Fitted Value Plot

DISCUSSIONS

- S/N ratio response suggest, moisture content (A) at level 1 (2.5%), green strength (B) at level 3 (950 g/cm^2) permeability no. (C) at level 3(265) and mould hardness no.(D) at level 3 , (90) are the optimum values for getting minimal defects in sand casting.
- Expected optimal range of defects is 2.09 < 3.47 < 4.85 means using the optimum parameter level the average defects would lie in the predicted optimal range.
- P value is less than 0.05 in the ANOVA table for parameters moisture content & green strength, therefore it can be concluded the parameters moisture content (A) and green strength (B) are the most significant parameters.
- The calculated values of F ratio are significantly larger then the critical value of F ratio of 4.97 for parameters moisture contents and green strength. Therefore it can be concluded that parameters green strength and moisture content significantly explain and affect the quality of casting.
- The total adjusted value of R square is 78.03 % which shows that 78.03 % of variation is explained by parameters A (Green Strength) and B (Moisture Content) because p value of C and D are greater than 0.05 therefore their effect is not that much significant as compared to A and B.
- After interpreting the main effect plots for means and S/N ratio we can clearly see that slope of A and B i.e Moisture content and green strength is high in comparison to other factors. Hence the most significant factors here are A and B.
- Permeability C has the least effect on the quality of casting.

CONCLUSIONS

Conclusion

- Taguchi's method for optimization is simple and effective in terms of time and cast of overall manufacturing operation performed. It improves the overall quality of product and helps in development at all stages of product life cycle starting from design to finishing of product therefore it helps in reducing the cast at a larger extent with the help of smaller resources.
- The analysis proves that by improving the quality by Taguchi's method of parameter design at lowest possible cast, it is possible to identify the optimum levels of signal factors at which the noise factors effect on the response parameters is less.
- The proximity of the results of predictions based on calculated S/N ratios and experimental value show that the Taguchi's method can be used successfully for both optimization and prediction in cast iron sand casting
- The result of this research is the optimised process parameters of the green sand casting process which results in minimum defects. The optimum process parameters levels are moisture content-2.5%, green strength-940g/cm^2, permeability number-265, mould hardness number-90. Also the experiments give a comprehensible picture of contribution of all factors taken to the variation in the green sand casting process, thus the quality can be improved without further investment.

- From the result of the research it is found that the use of Taguchi's method to the green sand casting process has the following contributions:
- Enhances the productivity of castings produced.
- Boosts stability of casting process. Before the applications of Taguchi's method, the parameters of the casting process were more random and not easy to control and hence the product quality has volatility problems. Taguchi's method yielded optimised control factors, resulting in superior product quality and stability.

FUTURE SCOPE

There are number of directions to pursue as future work, experimentation with the help of optimized parameters can help in improving the quality of castings and reduction of defects, this can also be used in industry to improve the overall quality. Further a neural network model can also be developed to map the complex non linear relationship between process parameters and quality characteristics.

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